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How to be a Successful Scientist

A Guide for Graduate Students, Postdocs, and Professors

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Preface

Working as a research scientist is one of the most satisfying and stimulating careers available. Your efforts may benefit humankind by advancing our understanding of the world, creating new products or processes, or solving complex problems. Going to work is often enjoyable, rather than being a drag. But research scientists need a broad range of skills to be successful, which they normally learn during their graduate studies. Typically, these skills are acquired slowly and in a piecemeal fashion as someone progresses through their graduate program. However, we believe that many of them can be gained much more rapidly and holistically by simply presenting them in a clear and concise manner. The purpose of this book is therefore to provide practical advice on how to be an effective research scientist, including managing your time, designing experiments, publishing scientific manuscripts, giving talks, writing grants, defending a graduate thesis, and much more. We mainly wrote this book with graduate students in mind, but our advice will also be valuable to others involved in scientific research, like postdocs, professors, government researchers, and industrial scientists. Our book has a unique perspective because it is written by three scientists from the same family who are at very different stages of their careers but are all passionate about science and its ability to transform our world. David Julian McClements is a distinguished professor who has been an academic for over three decades. He has written several books, published over a thousand scientific articles, given numerous talks, and mentored many students and postdocs. Jake McClements recently completed his PhD and started a career as an academic. Isobelle Farrell McClements is just at the beginning of her PhD journey. Together, we provide advice from different perspectives that we hope will be useful for those wanting to be more efficient and impactful scientists.

Photograph of David Julian McClements, Jake McClements, and Isobelle Farrell McClements in Northampton, Massachusetts (Summer 2023).

Amherst, MA, USA — David Julian McClements
Newcastle, UK — Jake McClements
Ithaca, NY, USA — Isobelle Farrell McClements

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this book, the authors used ChatGPT to find relevant information. After using this tool, the authors reviewed and edited the content and take full responsibility for the content of the final publication. We also used AI programs to draw many of the figures in the book (Midjourney and DALL-E).

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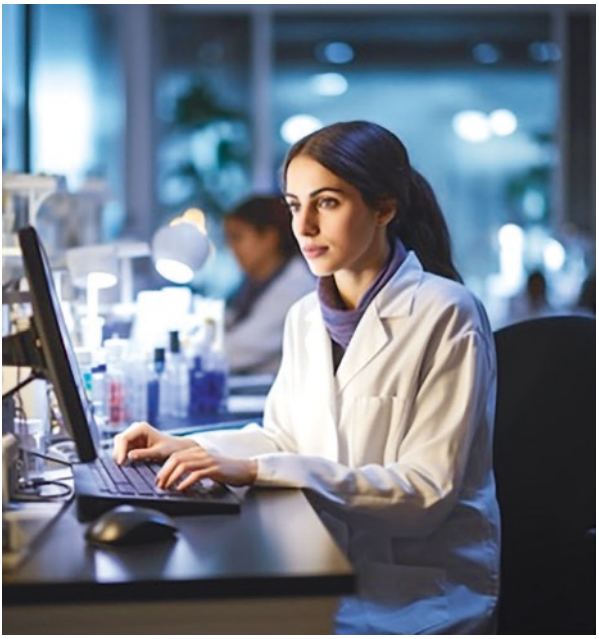
We would also like to thank the students, postdocs, visiting scientists, staff, and faculty in our departments for all of their support. Finally, we would like to thank everybody at Springer, especially Daniel Falatko, for believing in this project and helping to bring it to fruition.

Contents

Chapter 1
Setting Out on Your Academic Journey

Starting Your Graduate Career

This chapter is mainly targeted at graduate students beginning their academic journey. Starting your graduate studies is both exciting and scary. It is different from your undergraduate studies, where you mainly focused on taking classes and passing exams (and perhaps partying a lot). Now, you are responsible for your own research project, which requires a whole new set of skills. Some of you may have gained research experience during your undergraduate studies by working in a



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professor's laboratory. However, these projects only provide a glimpse into the graduate student experience because of the limited time available. This book is designed to give you an overview of the life of a graduate student and to provide you with some tips and tools that will help you succeed. However, what exactly do we mean by successful? Practically, we mean that you will finish your graduate studies on time with all the skills you need to succeed in the future. This includes creating a *curriculum vitae* that will be attractive to your future employers, whether in academia, industry, government, nonprofit organizations, or other areas depending on your career goals.

You need to do several things soon after you begin your graduate studies. Some of these are practical things, such as finding a place to live, establishing how you will get around, setting up a bank account, registering with a doctor and dentist, and finding out where the local supermarket and other shops are. Others are more directly related to your graduate studies:

- Becoming familiar with your graduate program.
- Getting to know your professor and lab mates.
- Establishing your research topic.
- Developing a good research philosophy.
- Thinking about your career goals.

Familiarizing Yourself with Graduate Program Expectations

Each department has somewhat different requirements for students to complete their graduate program. It is therefore important to establish precisely what your department requires for you to complete your graduate studies on time. Some of the most common elements in graduate programs include a qualifying exam, course work, teaching experience, scientific research, an oral exam, a written exam, a thesis proposal, and a final thesis defense. Most graduate programs do not contain all of these elements. However, it is important to find out what the expectations are in your department, as well as the timeline for completing each element. This information may be obtained from your department's website, from a student handbook, or by speaking to your professor or graduate program director. If your department does not provide one, we recommend you prepare a checklist containing all the major elements and when they need to be completed. An example checklist is shown in Table 1.1. You can then keep this checklist in your records and check off each element as you complete it.

In addition to being sure to complete the specific requirements of your graduate program, you may also want to set some goals for your research progress. For instance, you may want to write a review article in your first year or two, and then write one or more scientific manuscripts and present several talks in the following years (with the number depending on your research field).

Table 1.1 Example of a checklist containing the major elements needed to complete a graduate program in the United States. This checklist will vary for different universities and countries

Task to complete	Notes	Timeline (Time after starting)	Date completed
Course work	Required to pass 18 credits of graduate level classes	12–18 months	
Oral proposal exam	Prepare grant proposal and arrange to have four professors serve on oral examining committee.	18–24 months	
Establish thesis committee	Establish thesis committee. Arrange to have four professors serve on this committee.	18–24 months	
Thesis proposal	Write thesis proposal and give oral presentation to thesis committee.	1–2 years before finishing	
Final defense	Request advisor to send email to graduate program director about results of defense, date passed, and thesis committee member names.	4–5 years	

Choosing a Professor

In some cases, you may be assigned to work with a particular professor, or you may have to work for a particular professor because they are the only person who has funding to support your graduate studies. In other cases, you may have some flexibility in deciding which professor to work with. Therefore, how do you decide? There are several factors to consider, which can be mainly divided into field of study, productivity, environment, and personality (Fig. 1.1):

- *Field of study*: The professors in your department will work in a variety of different research areas. For instance, in a chemistry department, they may work in the general areas of organic, inorganic, physical, or analytical chemistry. They may also use their specific expertise to focus on particular topics, such as renewable energy, sustainable polymers, or drug delivery systems. Ideally, you should choose a topic you are passionate about. The more excited you are about your research, the easier it will be to put in the long hours of work needed over the next few years. You may also want to choose a topic that is compatible with your career goals. If you intend to become an academic, you might want to select a "hot topic" that is on the cutting edge of research and is likely to be important in the future. Universities often want to hire new faculty members who are doing pioneering research rather than those doing more traditional research. Conversely, if you intend to work in industry, you may want to work with a professor who will help you develop the skills needed. For instance, you can get experience with the fabrication and characterization methods typically used in the companies you would like to work for.
- *Productivity*: The research productivity of a professor is another crucial factor to consider when selecting a laboratory to work in. There are enormous variations in research output between different professors depending on their field of expertise, research group size, research philosophy, creativity, and efficiency. Some

Fig. 1.1 Choosing a professor with a personality, working culture, and productivity that match your needs can facilitate your graduate studies

professors only publish one paper every few years, whereas others publish multiple papers per year. Typically, it is better to work in a highly productive laboratory, as you will be involved in more research projects that lead to scientific publications. This will help to bolster your *curriculum vitae* and make you more competitive when you look for your next job. However, some professors (especially those working at highly competitive universities) focus on publishing high-impact manuscripts, such as those that appear in prestigious journals such as *Nature* or *Science.* These manuscripts often require many years of hard work involving numerous people because the problems being addressed are so complex and at the outer edges of our knowledge. Being part of one of these manuscripts can greatly increase your reputation. However, this is high-risk/high-reward research, and there is no guarantee that it will lead to findings that will be published in one of these prestigious journals. Even so, some people are really passionate about this kind of research and are willing to take the risk. For other people, it may be safer to choose a topic that is more likely to lead to results that will be publishable. In general, it is a good idea to do some background research on the number and quality of scientific papers being published by different professors in your department when selecting the most appropriate one to

work with. This can be done using literature database search programs such as Web of Science, Scopus, or Google Scholar. Often, assistant professors who are working toward tenure have the strongest motivation to publish, but they also have to establish their labs and research programs, which can take some time. It may also be possible to obtain some insights into the productivity of a research group by checking the number of papers that the group members have published by the end of their PhD degrees, which can also be done using these database search programs.

- *Culture*: Professors also foster different working environments within their research groups, which can greatly impact your experience during your graduate studies, including your chance to develop the skills you need to succeed. Some researchers in highly successful and well-funded laboratories have enormous lab groups, sometimes with more than 50 people. As a result, it may be difficult to see your professor very often, and so you do not get much direct mentorship. In contrast, other laboratories may only contain a few students and postdocs, so you may have a much better chance of getting to know your professor and receiving more guidance. Professors also vary in the frequency of individual and group meetings that they expect to have with their graduate students. Some professors may hold meetings with students every week or two, whereas others only expect to meet the student when they have a specific problem or question. Some professors actively mentor their students and ensure they develop the knowledge and skills they require for the rest of their careers, whereas others leave it up to the students to work it out for themselves. You should therefore find out what the working environments of the different professors in your department are and then identify one that suits your goals and personality. This can be done by speaking with the professors or the people who work in their laboratories. For instance, you could find the contact information of students working in different professors' laboratories and contact them by email or social media before you arrive in your new department.*Personality*: Professors are people, and like all people, they vary greatly in their personalities. Some professors can be kind, supportive, and encouraging, whereas others can be mean, uncaring, and demanding. Some professors may be relatively flexible and give you time off when you need it, whereas others may expect you to be in the laboratory all the time. Again, you want to find a professor whose personality and work expectations match your needs. You can often get some idea about this by talking to other students and postdocs in the department who have worked with the professor before. Alternatively, you can speak with the professor themselves. You may be willing to work with someone who has a bad reputation if they are a superstar scientist who may advance your career. However, be sure to think about this when deciding who to work with. Poor student-supervisor relationships are one of the main reasons why graduate students fail to complete their degrees, as well as for student mental health problems.

Getting to Know Your Lab Mates

After starting your graduate studies, you may work in the same department and research group for several years. It is therefore important that you establish a good working relationship with your professors and lab mates (Fig. 1.2). In addition, your lab mates may be people you can hang out with in your spare time. Your lab mates may include technicians, postdoctoral research fellows (postdocs), visiting scholars, PhD students, Master's students, and undergraduate students. For those unfamiliar with the different kinds of people who typically work in academic research laboratories and their different roles, we give a brief overview here (if you already know this, just skip to the next section).

Your Professor

Typically, professors are very busy people who have many duties, as well as supervising and mentoring the members of their research team. They may have to prepare and teach classes, write scientific manuscripts and grants, attend scientific meetings,

Fig. 1.2 It is important to get to know and develop a good working relationship with your professor and lab mates

serve on departmental or university committees, work with government agencies, consult with industry, and perform various other tasks. Consequently, you should plan your interactions with your professor carefully, so your meetings are efficient and effective. Make sure you are well prepared for each meeting and have specific questions you want to ask. It is a good rule of thumb to have at least attempted to find an answer to your question before asking your professor. Once you have settled into the department, contact your professor (usually by email) and ask them for a first meeting. They may explain the graduate program to you and the expectations required of a graduate student working in their lab. They may also introduce you to the research topic you will work on. Sometimes, this may be a very well-defined topic, but other times they may ask for your input. Therefore, have an idea about what kind of research you might be passionate about working on before your first meeting.

Your Lab Mates

Technicians are often permanent employees of the university that are responsible for the general management of research laboratories. They help to orientate and train new students, order chemicals, supplies, and equipment, and ensure that the laboratory is clean, safe, and runs smoothly. Postdocs are people who have already completed their PhD studies and are now working for a professor on a specific research topic. They do not need to take any more exams, but they are often highly motivated to perform research that will lead to scientific publications because they may want to become professors themselves. As a result, they want to build a strong resume that will make them competitive when a professor position opens up somewhere. For this reason, working with postdocs is often a good idea because they have a strong incentive to publish scientific manuscripts. Visiting scholars may be students, postdocs, or professors who come from another university, often international, who are working in the laboratory on a specific topic. Interacting with them is a nice way to learn more about people from different countries and cultures, which can greatly enrich your graduate study experience. Graduate and undergraduate students working in your laboratory may be doing projects similar or different from yours. It is crucial to talk to these students to find out what they are doing. Then, you can identify people who can help you with your research and make sure you are doing something sufficiently different from them. If your projects overlap too much, it will be more difficult for you to publish your research independently. PhD students typically work for 3–6 years, Masters students for 1–2 years, and undergraduates for a semester or two. It is advisable to identify the most senior PhD students working in a similar area to you, as they will have the most knowledge and experience and will most likely be able to advise you. For instance, they can help to teach you the different analytical instruments, experimental protocols, and data analysis techniques needed in your own studies.

Finding a Mentor

Starting a graduate program can be daunting, confusing, and overwhelming. It is therefore a good idea to identify a mentor who has been through the process before because they can provide you with advice and support. This is usually someone in your lab group who is a senior graduate student or postdoc. You could speak to your professor about recommending a suitable mentor for you. You may even want to have a mentor outside the university who can help you with your career development, like a research scientist who works in industry. A mentor can provide practical advice such as where to order chemicals or who to ask to use a piece of equipment in the laboratory. They may also provide you with emotional support if you are feeling overwhelmed or stressed.

Timing – How Long Will It Take?

The length of your graduate studies can vary considerably depending on your topic, professor, department, location, funding source, and how rapidly your research progresses. Typically, however, a PhD takes approximately 3–6 years. Ideally, you want to complete your studies as soon as possible, then you can move on to the next stage of your career. On the other hand, you want to build a good *curriculum vitae* to help you secure your next position. You may therefore need to publish articles in academic journals, give presentations at conferences, and (when possible) win awards or scholarships. Typically, your research productivity and output increase as you progress through your PhD, so you tend to publish and present more in the later stages of your graduate studies. For this reason, it may be beneficial to stay for a longer time, so you can build a stronger *curriculum vitae*. However, this depends on their being sufficient financial support available to continue your studies. The bottom line is that you want to be as productive as possible throughout your PhD to finish in good time, with as many accomplishments as possible.

Developing the Skills You Need for Your Future Career

You should use your time as a graduate student to develop the diverse range of skills you will need to be successful throughout your career. It is important to become an expert in your specialized field of study, which means you need to learn the theoretical principles, analytical instrumentation, experimental protocols, and data analysis methods needed in this field. However, numerous other "soft" skills are also important to becoming a successful scientist, which you should also try to develop. These skills include time management, creativity, critical thinking, communication, independence, teamwork, literature searching, and resilience.

Time Management

Throughout your graduate studies you may have multiple tasks to complete, including taking classes, teaching classes, preparing for exams, carrying out research, analyzing data, presenting results, attending conferences, and preparing oral presentations. All of these tasks put demands on your time. It is therefore extremely important to develop good time management skills so you can achieve your goals. First, make a list of all the tasks you need to accomplish. Second, rank the different tasks according to their importance (high/low importance) and urgency (high/low urgency) (Fig. 1.3). Third, look at the time you have available in your calendar. Work on the urgent and important tasks first, leave the unimportant and nonurgent ones to last (or don't do them at all if they are not really necessary). An important skill is learning when to say "no." You may get asked to do a lot of things that are not critical to completing your graduate studies - be prepared to turn them down if necessary. We briefly give some tips for handling different tasks below:

- *Important and urgent*: If possible, do these tasks as quickly as you can. Set aside a block of time, focus, and get them finished promptly. Examples of this kind of task are completing a class assignment or take-home exam, as well as responding to the reviewer's comments on a scientific manuscript.
- *Important but not urgent*: These are important tasks that do not need to be done immediately. Look at your calendar and schedule a time when you can work on these tasks. Examples of this kind of task are writing a scientific manuscript,

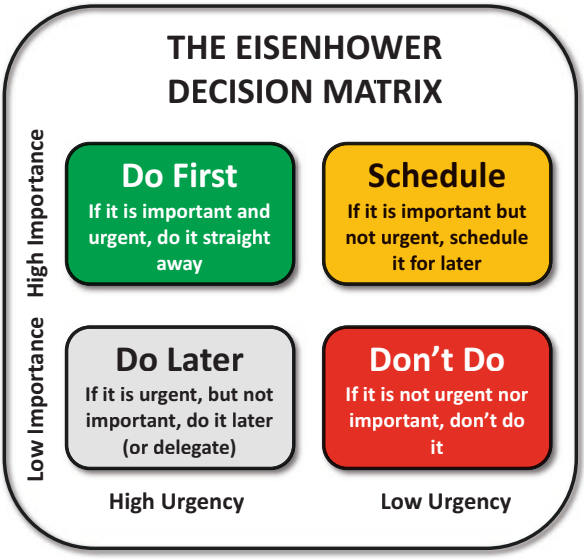

Fig. 1.3 The Eisenhower decision-making matrix can help with time management and prioritizing tasks

preparing for a presentation at a conference, or writing your thesis. These tasks can be added to a list of things to do and then worked on when you have free time. Then, when they do become urgent, you will already have made some progress on them.

- *Not important but urgent*: Some tasks may not be essential but have a short deadline. First, decide whether you need to do these tasks at all. Turning them down or delegating them to someone else may be possible. If you do need to do them, then work on your important and urgent tasks first, and then work on these ones. As an example, there may be a seminar in your university that is on a subject that is far from your field of expertise. The seminar may be taking place soon, but you have another urgent and important task to complete. In this case, you want to skip the seminar, as it will not significantly impact your graduate studies. However, if you have more time, attending may be beneficial because it would broaden your knowledge.
- *Not important and not urgent*: Some tasks are not important and not urgent. You can often ignore these tasks. This kind of task might be reorganizing the books on your bookshelf to put them into alphabetical order or checking your social media posts every 5 min.

During your graduate studies, you may be overwhelmed with many different demands. Taking time out for yourself is always important to ensure that you maintain your mental health and well-being. You may be able to do some of your academic tasks in a social environment, such as answering your emails or reading scientific papers in a café, which can be more fun than working in the lab all the time. It is also important to take time completely away from work, such as hiking, working out, doing a sport, traveling, or going to the pub, café, or restaurant with your friends. Typically, you will be a much more efficient, effective, and happier researcher if you take some quality time away from work.

Creativity

Important advances in science often depend on the creativity of the individuals involved. If your goal is to become a professor, to start a business, or to work for an innovative company, then it is often important to be able to think creatively and generate new ideas. Some people seem to be naturally more creative than others, but it is a skill that can be developed and improved. In general, creativity involves coming up with novel and valuable ideas (such as a nonstick frying pan) rather than novel ideas that are not useful (such as a frying pan made of ice). The origin of creativity is a complex topic that is not fully understood and depends on both biological and social factors. We all possess some level of creativity because it is hardwired into us through evolutionary pressures – our ancestors were those people who could creatively solve problems in their environment and therefore be more likely to survive and procreate. Creativity also depends on a person's exposure to diverse

experiences, cultures, and social interactions throughout life. Some societies and places are more accepting and encouraging of diversity than others, which can stimulate creative thinking. Typically, creativity relies on developing a deep understanding of the area you are working in (as well as other areas) and then entering into a state of mind that allows your unconscious to recombine your knowledge and ideas in novel ways. This means that it is crucial to read many scientific papers and books and to attend scientific talks in your research field and related areas. Often, an idea that is commonplace in another field can be brought into your research field, leading to new advances.

Critical Thinking

Critical thinking is an important tool to develop during your graduate studies. It involves questioning the assumptions underlying your and others research, carefully assessing evidence to ensure the research was designed, performed, and interpreted appropriately, and considering problems from alternative perspectives. As an example, at the beginning of one's career, it is common to assume that everything you read in scientific articles or hear at scientific conferences is correct. However, researchers, reviewers, and editors can make mistakes, and so it is important to critically assess any materials you are utilizing within your own research. Thinking critically about other people's work helps you to think critically about your own, which can help to prevent you from making silly mistakes.

Communication

The ability to communicate with different audiences in oral, visual, and written formats is critical to being a good scientist and advancing your career. There is no point doing important scientific work if nobody finds out about it. You should therefore be sure to develop good communication skills throughout your graduate studies. The best way to do this is by writing scientific papers, preparing posters, and giving talks at lab meetings, classes, and conferences. There may be resources at your campus that can help you develop effective communication skills, such as career development centers. There are numerous books on developing good speaking and writing skills (see resources at the end of this chapter).

Writing is a critical skill for scientific researchers because most science is communicated through manuscripts and published in scientific journals. You should therefore pay particular attention to developing effective writing skills. Your writing should be informative, engaging, and concise. Tips on writing scientific manuscripts and developing good writing skills are given later in this book (Chap. 6). Other forms of communication are also important for academics, including speaking and graphics. You may be asked to present your research findings in the form of a talk or

a poster at lab meetings, scientific conferences, industrial events, or as part of your exams. Tips for preparing oral presentations and posters are also provided later in this book (Chap. 9). Developing an engaging speaking style can help get you and your research recognized by other scientists in your field, who may be potential future employers. If they are impressed with the quality of your talk, they are more likely to hire you in the future.

Having good graphics skills is also essential for effective and impactful scientists. Many scientific journals require authors to submit a graphical abstract with their manuscripts, a single image that captures the essence of the research. A high-quality image can attract readers to your work and increase its impact (Fig. 1.4). Moreover, some scientific journals invite authors to submit a visually engaging image that may be used as the cover of the journal, further increasing the impact of your work. Good images can also greatly increase the comprehension and impact of your scientific papers, posters, and talks, enhancing your visibility in your field of expertise. Again, this helps increase your scientific reputation and may help you get your next job. There are different kinds of computer programs that can help you

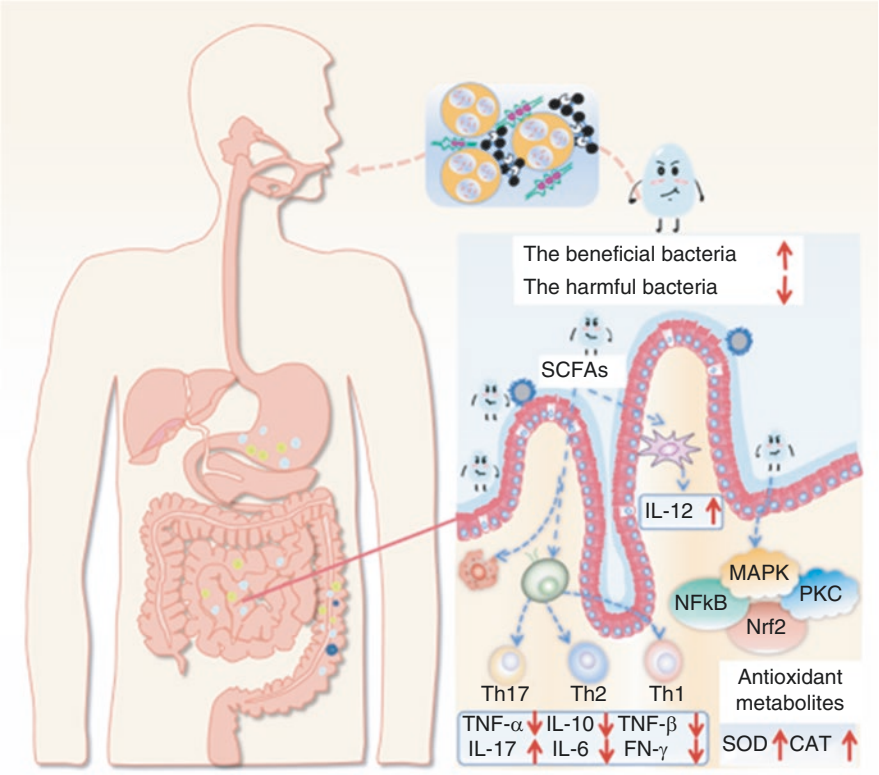

Fig. 1.4 Having the ability to create engaging and informative images can greatly enhance the impact of your scientific research. (Image from Gu and coworkers (with permission) (Gu et al. 2022))

create visually impactful images, such as Microsoft PowerPoint, Adobe Illustrator, or Adobe Photoshop. In addition, artificial intelligence programs (such as Midjourney) are becoming increasingly good at creating images, such as some of those shown in this chapter. It is advisable to become familiar with one or more of these graphical design programs to increase the impact of your research. In the future, other forms of communication may become more important, such as online videos or podcasts.

Independence

If you are pursuing a graduate program, you will likely become a future leader in your field. For example, you may become a professor, a manager, an entrepreneur, or a government official. It is therefore critical that you develop the skills needed to think and act independently. By the end of your graduate studies, you should be able to come up with original ideas, design and perform experiments, analyze the results, and communicate your findings. This may seem daunting when you start your graduate studies, but you should actively work to develop independence as you progress through your degree. This may be achieved by brainstorming new ideas with your professor or lab mates, helping to design experiments yourself, writing the first draft of scientific manuscripts, helping to revise manuscripts after they have been reviewed by academic journals, and volunteering to give scientific presentations.

Teamwork

Scientific knowledge has expanded enormously over the past century, and it is often difficult for a single individual to make transformative advances on their own. Many areas of science are extremely complicated and benefit from multidisciplinary teams that involve numerous people with complementary skills to solve complex problems. It is therefore important for you to be able to identify situations where a team approach would be beneficial to solve a problem, as well as to identify potential collaborators, put together a team, and work with other people effectively. This may often be the main responsibility of a professor leading the research, but graduate students may also be involved as part of the team. Several factors are important to successfully working in teams. You need to ascertain precisely what your role is in the team and what is expected from you. You should make sure you finish any tasks assigned to you on time, so you are not holding up other people in your team. You also need to respect everybody else's time – don't hold meetings or ask for detailed information unless it is absolutely necessary. You need to have an open mind when listening to other people's perspectives but also be prepared to promote your own perspective. People working in different scientific disciplines have different knowledge, approaches, and skill sets. It is crucial to appreciate this and be willing to learn